SOIL MICROMORPHOLOGY

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ABSTRACT

Soil micromorphology is a tool for studying a part of the continuum, from landscapes to microvoids between soil particles. Methods are outlined for sampling soils and preparing thin sections for study under the microscope. Features such as voids, aggregates, coatings, mineral and organic particles and their arrangements are shown and described briefly. The potential is outlined for applications of soil micromorphology to studies of soil genesis and of the influence of fauna on soil properties. The annotated reference list aids interested readers to delve farther into the fascinating architecture of soil as viewed in thin sections rather than as amorphous dirt.

RÉSUMÉ

La micromorphologie des sols représente un outil permettant d'étudier une partie du continuum de la morphologie des sols, qui s'étend des paysages jusqu'aux espaces microscopiques entres les particules. Les auteurs exposent dans leur grandes lignes des méthodes pour échantillonner les sols et pour préparer des coupes fines pour étude au microscope. Ils montrent et décrivent brièvement certaines particularités des sols telles que des vides, des agrégats, des pellicules, des particules minérales et organiques et leurs arrangements. Ils discutent du potentiel qu'offrent diverses applications de la micromorphologie des sols dans l'étude de la genèse des sols et de l'influence de la faune sur les propriétés des sols. Une liste de références commentées aidera les lecteurs intéressés à se familiariser davantage avec le sujet fascinant de l'architecture des sols tels qu'observés en coupes minces, plutôt que comme amas de terre amorphe.

INTRODUCTION

Soil micromorphology is the sub-discipline of soil science that includes studies of the structure of relatively undisturbed soil samples with the aid of microscopes. It is part of continuum that begins with observations of the pattern of soils in the landscape, proceeds to studies of pedons (units of soil) representative of segments of that landscape, continues with description and sampling of horizons within those pedons, of aggregates within the horizons, and so on at increasing detail, to the study of features within aggregates as seen in thin sections with the microscope (Fig. 1). Soil features ranging in size from approximately 10 to 10,000 μm can be studied in this section with the polarizing microscope. Scanning electron microscopy (SEM) is applied to the study of smaller features (Bisdom, 1981).

Micromorphological techniques were applied rarely in the study of soils prior to the publication of the book 'Micropedology' (Kubiena, 1938). The use of micromorphology

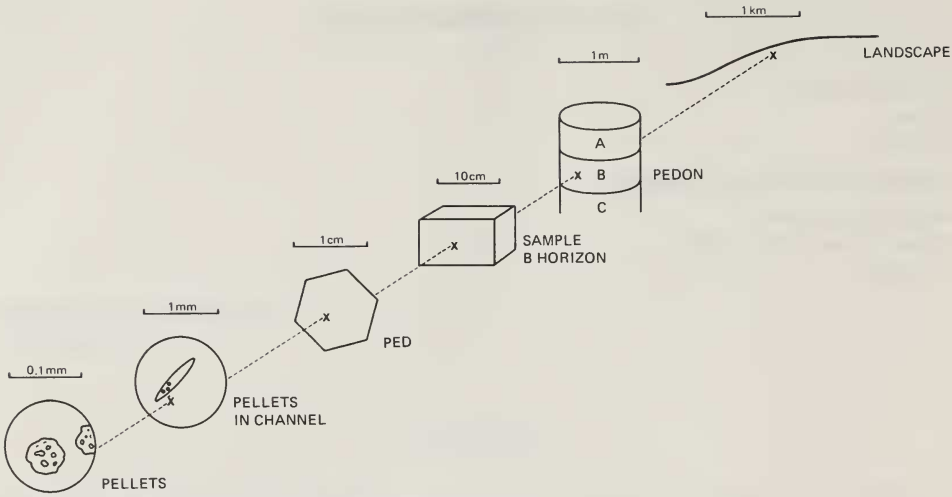

Fig. 1. Diagrammatic sketch indicating that soil micromorphology is a part of a continuum that includes macromorphology of soils in the landscape.

increased slowly until after the publication of Brewer's (1964) book "Fabric and Mineral Analysis of Soils". In it, Brewer defined terms precisely and outlined a system for describing soil microstructure; the book continues to be a basic reference. Currently, many soil scientists use micromorphological techniques in studies of soil genesis, physics, chemistry, minerals and living organisms. Only a few, however, specialize in micromorphology.

In this paper we outline the steps involved in sampling, in preparation of soil samples for study, and in applying micromorphological techniques to the study of soils. Examples are given of kinds of problems amenable to study by micromorphology; some involving soil fauna and related to soil structure are included. Further information on all aspects of soil micromorphology is included in the references listed.

SAMPLING

Sampling is a crucial step in micromorphology. The first step is to decide the purpose of the study. Suppose, for example, that the pedologist wants to determine the nature of the material that cements the sand grains in a cemented horizon of a sandy pedon. A single clod of the cemented material might be an adequate sample for preparation of a thin section, description by microscopy of the material that links the grains, and analysis of the material by energy dispersive X-ray analysis (Bisdom, 1981). If, on the other hand, the purpose of a study is to determine differences in microstructure of surface horizons associated with differences in land use, a systematic sampling plan involving replication of samples of similar soils under different land use would be required.

After establishing the purpose and deciding on the sampling plan, the next step is to collect the samples. The fundamental requirement is to obtain samples without altering the soil fabric, the arrangement of particles and voids. For unconsolidated mineral soil materials, this is usually done by pushing a metal frame or an open metal box, a Kubiena box, into the horizon to be sampled. Boxes of different sizes are used depending on habits, purpose of the study, and nature of the soil. We use metal frames 8 x 6 x 5 cm, 8 x 6 x 2.5 cm and 6 x 4 x 2.5 cm made from 20 gauge galvanized iron with the largest faces, 6 x 8 or 6 x 4 cm, open. The frame may be pushed by hand or preferably jacked into a vertical or horizontal exposure of the horizon of interest. The sample is trimmed flush with the edges of the frame, and its orientation is marked on the metal frame. The trimmed sample is placed in a plastic bag to avoid loss of water, and the open faces are covered with 9 x 7 cm pieces of plywood which are taped securely in place. The site number and sample depth are marked on the sample with waterproof ink. Information on the site and the sample is recorded in either a notebook, or a form such as a CanSIS file form for soil data (Day, ed. 1982).

If the horizon to be sampled is strongly coherent, such as a cemented horizon, a clod may be broken out, placed in a plastic bag, taped and labelled as indicated. Organic soil samples such as peat may be obtained with a Macaulay sampler, which provides half a cylindrical sample approximately 3.5 cm in diameter. These samples are placed in half cylinders of 3.75 cm PVC piping, enclosed in a plastic bag, protected with a wooden cover, taped and labelled. Further information on sampling is available (Sheldrick, 1984).

PREPARING SAMPLES FOR MICROMORPHOLOGICAL STUDY

Stereomicroscope

For some purposes such as describing the shapes and sizes of aggregates smaller than 2 mm, it is useful to examine samples under a stereomicroscope at magnifications of 5 to 30x. Such data complement macromorphological information obtained in the field.

Impregnating Samples for Preparation of Thin Sections

Most soil materials are unconsolidated so it is necessary to consolidate them by filling the pores with plastic and hardening before preparing thin (20 or 30 μm) sections. Water must be removed prior to impregnating the soil with most of the plastics that are used. Three methods have been used for removing water (Murphy, 1983): (1) oven drying - this results in shrinkage of many soil materials and hence alteration of pore sizes, (2) freeze drying - this results in ice crystal formation within the sample and, hence, some disruption of the fabric, (3) exchange of water by acetone - this results in some dissolution of organic components but it is the best of the three methods for preserving the soil fabric. Details of the drying procedues are given by Fitzpatrick (1984), Sheldrick (1984) and references cited therein.

After water is removed by oven - or freeze-drying, the sample is put under vacuum so as to remove air from voids, and the plastic mixture is added under vacuum. For acetone-exchanged samples, voids are filled with acetone so vacuum is not necessary during the addition of plastic. A variety of polyester resins diluted with thinners such as acetone, or epoxy resins, are used (see Jongerius and& Heintzberger, 1975; Sheldrick, 1984; Fitzpatrick, 1984). Catalysts may be added to increase the rate of polymerization and fluorescent dyes may be added to facilitate study of pores. We use a polyester resin - acetone mixture; Uvitex OB (Ciba-Geigy), a compound that fluoresces in ultraviolet light, is added in some studies (Sheldrick, 1984). Usually in our laboratory 2 weeks to 2 months are required from the time the resin is added until the impregnated block is hard. For some purposes, it is appropriate to use a resin mixture that hardens in a few hours. Final curing of the plastic is done by heating the block to 60°C.

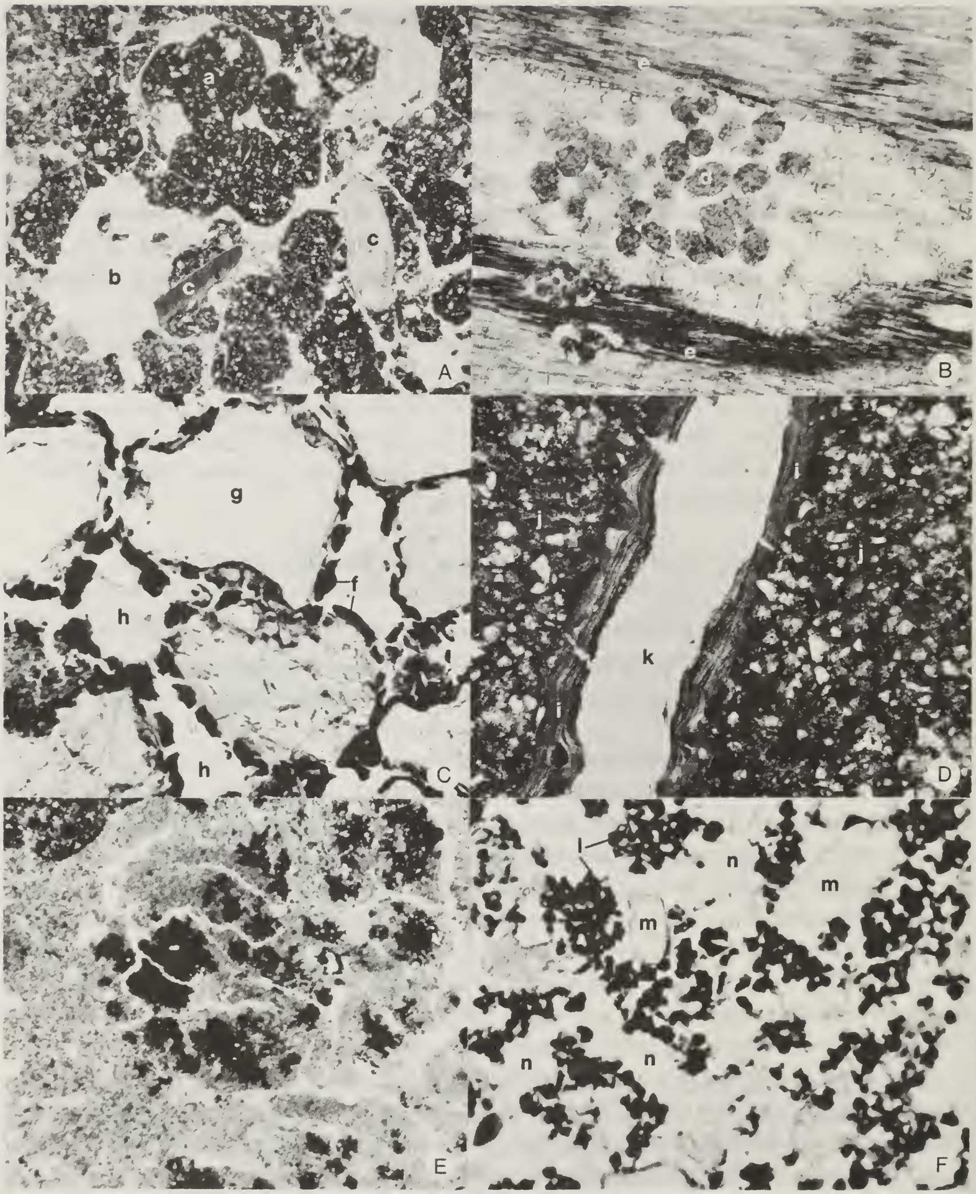

Fig. 2. Photomicrographs of features in soil thin sections. A. Partly-fused, rounded aggregate 'a' due to earthworms, a large void 'b' and organic fragment 'c' in the Ah horizon of a clayey Hunic Gleysol near Ottawa. The width of the field is 8 mm. B. Fecal pellets 'd' of mites in decaying wood tissue 'e' from an Om horizon of an organic soil in Ontario. The width of the field is 1.3 mm. C. Dark reddish-brown, amorphous coatings 'f' on sand grains 'g', and packing voids 'h' in the Bhc horizon of an Ortstein Humic Podzol from New Brunswick. The width of the field is 1.3 mm. D. Clay coating 'i' on surfaces of dense clayey peds with embedded silt and sand grains 'j' and a planar void 'k' in the Bt horizon of an Orthic Gray Luvisol from Ontario. The width of the field is 1.3 mm. E. Reddish-brown and black nodules enriched in Fe or Mn, of Fe and Mn in the Bg horizon of an Orthic Humic Gleysol from the Fraser Valley, British Columbia. The field is 3.9 mm wide. F. Dark reddish-brown aggregates '1' in spaces between sand grains 'm' in a porous 'n' Bf horizon on an Orthic Humo-Ferric Podzol from Québec. The width of the field is 1.3 mm.

Preparing Thin Sections

The hardened sample is cut with a diamond saw to obtain a horizontally or vertically oriented slab depending on requirements, approximately 1 cm thick. For samples containing Uvitex OB, the cut face of the block may be photographed under ultraviolet light to show the pore pattern. Pore configuration may be characterized quantitatively using an image analyzer (Murphy, 1982; Bullock and Murphy, 1983). The sample orientation and number is marked on the slab and the area to be used for thin sections is selected. The dimensions of the thin section may be as large as the block or approximately 2 x 3 cm depending on the equipment available and the purpose of the work. A chip of the appropriate size is cut, its orientation is marked, one side is ground smooth on a diamond lap and cleaned. The chip is warmed on a hot plate, epoxy cement is applied and a glass slide is fixed to the chip. The mounted chip is cut to a thickness of approximately 0.5 mm on a diamond saw. It is ground on diamond laps with progressively finer grit to a thickness of 20 to 30 μm. The thickness is checked by observing the section under crossed polarizers with a polarizing microscope. Quartz grains appear white to grey if the thickness is correct. The section is cleaned, a cover glass is applied with epoxy, and the sample orientation and number are marked on the microscope slide.

Describing Thin Sections

Systems for describing thin sections are outlined in several publications (Brewer, 1964; FitzPatrick, 1984; Bullock *et al.*, 1985). We refer to the last system as it was developed by an international committee. Sections are described under the following headings:

Microstructure.— The size, shape and arrangement of particles and voids. For example, note the rounded aggregates, large voids and organic fragments in an Ah horizon (Fig. 2A).

Mineral and Organic components.— Mineral grains larger than approximately 20 μm can be identified by skilled microscopists. The nature and degree of decomposition of organic components may be identified. For example Fig. 2B shows a decaying woody root fragment with a cluster of mite pellets.

Groundmass.— The proportions and arrangements of coarse and fine components. In some samples, the fine material occurs as coatings on coarse grains (Fig. 2C); in others coarse grains are imbedded in a fine matrix (Fig. 2D).

Pedofeatures.— Features of the fabric due to soil genesis. For example, the coating of clay on the heterogeneous matrix material adjacent to the planar void (Fig. 2D) is a pedofeature due to deposition of clay from suspension. The dark brown and black nodules (Fig. 2E) are pedofeatures due to segregation of Fe and Mn oxides in a soil that is saturated and under reducing conditions periodically. The microaggregates in the B horizon of a Podzolic soil may be due to physical processes or to soil fauna (Fig. 2F).

APPLICATIONS OF SOIL MICROMORPHOLOGY

Soil micromorphology has been applied principally to studies of soil genesis. In recent years, however, applications to other areas of soil science, including soil zoology, have increased markedly. Some examples of these applications are discussed briefly; others are found in Bullock and Murphy (1983) and in proceedings of previous meetings of the International Working Meeting on Soil Micromorphology.

Among the major applications of soil micromorphology in studies of soil genesis is seeking direct evidence of translocation of fine particules from near-surface to subsurface horizons (see papers in Bullock and Murphy, 1983; and Douglas, 1985). Surfaces of peds in horizons from which clay has been removed are commonly uncoated or they may have coatings of coarser grains due to loss of clay. Horizons in which clay has been deposited commonly have surfaces of peds coated with oriented clay which appears finer and more uniform than the matrix material (Fig. 2D). Micromorphology has been applied also in many studies of podzols, especially their B horizons in which amorphous organic Fe, Al materials accumulate as coatings (Fig. 1C), as aggregates between grains (Fig. 2F), or both. A controversy continues over the origin of the aggregates (Fig. 2F). Some believe that they are fecal pellets; others believe that they are the result of physical processes, especially shrinkage on drying of the gel-like amorphous materials.

Micromorphology may be applied to soils studies other than those focused on genesis; a few examples are listed. Micromorphological and associated sub-microscopic techniques are powerful tools for studying the weathering of minerals in soils (Bisdom, 1981). Attempts have been made to relate the sizes and shapes of voids seen in thin section to water flow in soils (Bouma *et al.*, 1979), Babel (1975) has shown the potential of micromorphological techniques in studying, at high magnification, the decomposition of organic materials. Fox (1984) outlined a system for describing the complexity of organic materials at a wide range of magnifications. Other examples are given in proceedings of this symposium.

Kubiena (1938) was ahead of his time in recognizing the influence of soil fauna on structure and he observed soil fauna directly in the field. Bal (1982) reviewed the literature on the subject and reported results of his experiments showing faunal effects on soil structure. The growing awareness in North America of the role of soil fauna will be accelerated by this symposium. Many questions regarding the origin of aggregates and tubules in soils remain to be resolved and caution will be required to avoid overstating the roles of soil fauna. Hypotheses that could account for the common presence of rounded aggregates ranging in size from approximately 20 μm to several mm must be tested objectively for different soil horizons. Micromorphology will be a useful tool in such studies.

CONCLUSION

Examination of thin sections with the microscope complemented by submicroscopic techniques leaves the observer with an expanded appreciation of the organized heterogeneity of soil horizons. Soil samples prepared for chemical analysis appear to be amorphous dust. Thin sections show the complex architecture of a host of different mineral crystals, aggregates of fine particles, amorphous components and voids of differing sizes and shapes, some of them made by soil fauna. Having viewed soil in thin section, the observer incorporates into his model of soil the concept of its complex architecture and appreciates the influence of biological forces on that architecture.

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